# CHEMICAL BATCH SEQUENCER—A COMPUTERISED DECISION AID FOR SEQUENCING OF BATCH CHEMICAL PROCESSES

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by

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## CERTIFICATE

It is certified that the work entitled ' ' CHEMICAL BATCH SEQUENCER - A Computerised Decision Aid for Sequencing of Chemical Batch Processes ' has been carried out by Shri Bedanta.A. Das under our supervision and has not been submitted elsewhere for a degree.

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## ABSTRACT

Short-term planning ina batch chemical industry, poses an interesting problem. The objective is to select an optimal sequence and to schedule the process tasks involved in the time scale so that various constraints arising out of precedence structures, utility and equipment availability, chemical stability etc. are not violated.

In this study, an user friendly, computerised sequencer specific to the needs of batch chemical plant is developed. As usually the objective for evaluation of such scheduling varies from organisation to organisation and from problem to problem in the same organisation, the schedules are evaluated using a generalised cost function. This generalised cost function includes costs for inventory of raw materials and finished products, backorder cost, change over cost and utility costs including labour. Decision maker has the choice to provide appropriate weightages to the different cost components and thus can tailor it to suit his specific problem.

A set of heuristics and exact methods has been built in the program for sequencing. User has choice of these methods and can select ~~any one of them~~ the method best suited for

his problem. The Batch Sequencer developed in this study provides a decision aid which can be used interactively by the user who may not have in-depth knowledge of the sequencing methods but can effectively use his experience and judgement to choose the most appropriate sequence.

# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION:

From the days of alchemist, batch production has been an accepted mode for manufacturing variety of chemicals. Though continuously operated units dominate the large tonnage production of chemicals, valuewise significant portion of chemicals is still manufactured in batch plants on economic grounds. Typically pharmaceuticals, fine chemicals, cosmetics and food industries utilies batch, semi-batch and semi-continuous facilities. The batch processing system is characterised by:

(i) process specifications for each product giving necessary tasks and the sequence in which they must be carried out,

(ii) set of equipment items that can be used to carry out the various tasks,

(iii) demand patterns for the different products which may be distributed over time,

(iv) low tonnage production requirement.

Economical infeasibility of single product batch plants calls for the plant which can produce more than one product. For better efficiency and flexibility, standardised types of equipments are used which can be easily adopted, and if necessary, reconfigured to produce many different products. Depending upon structure of production, such batch plants are divided into three categories Rippin (1983b):

(i) Multi-purpose plants

(ii) Multi-product plants, and

(iii) Multi-plants.

A Multi-purpose plant can accomodate several different products at the same time. The same product may follow different routes through the plant at different times (figure 1a ). These alternative routes may or may not be predefined.

In a Multi-product plant, number of products are produced successively in a sequence of single product campaigns. For each product only one route is followed through the plant (figure 1b ).

A Multi-plant structure consists of two or more independent Multi-product plants operating in parellal. This type of production structure may have the advantage of

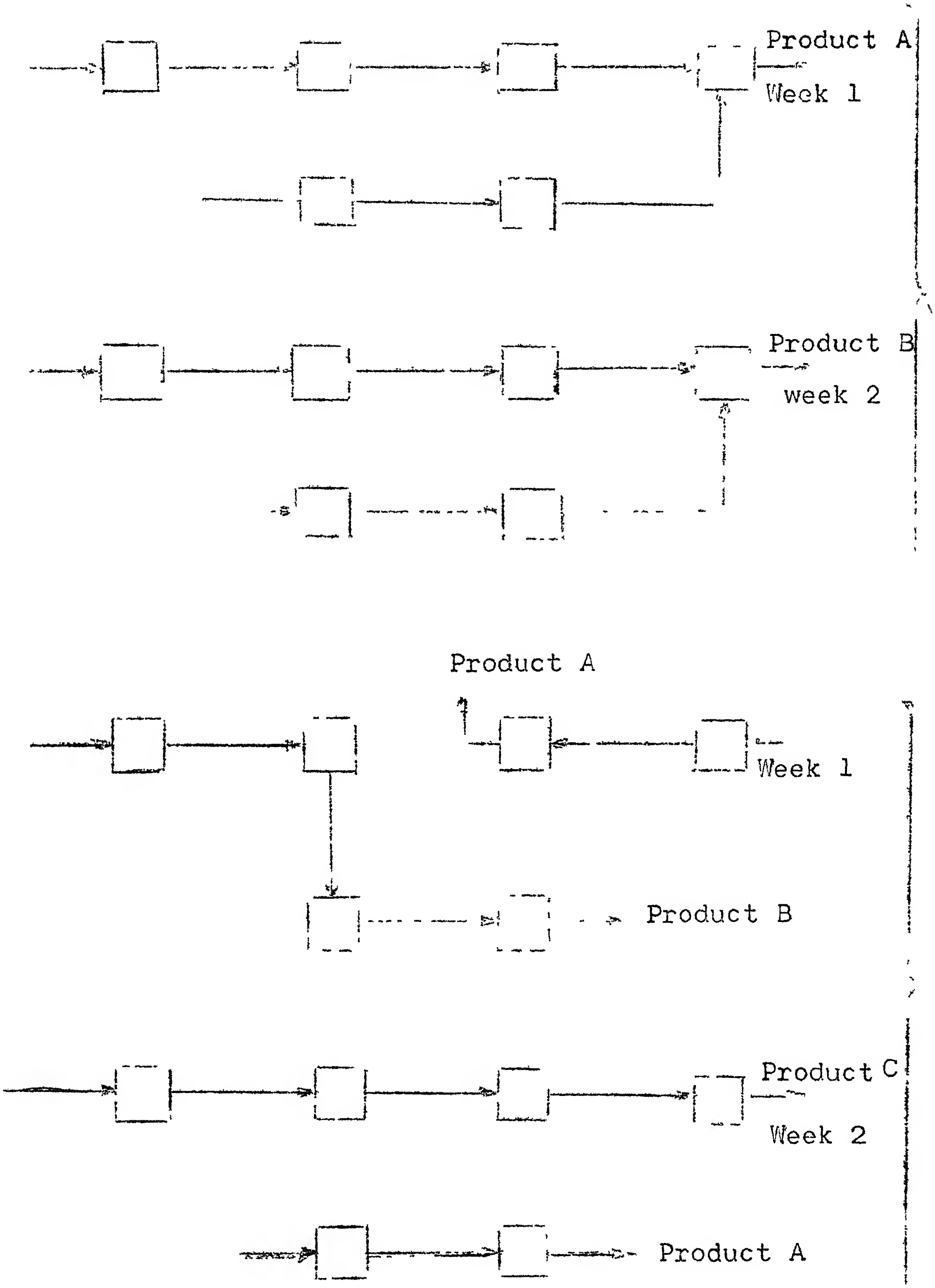


Fig. 1 - Multi-product batch plant (a)
and Multi-purpose batch plant (b)
(From Sparrow et al. (1974)).

allowing products with similar time and capacity requirements to be grouped together and also lead to savings in inventory charges but at the cost of the loss of economy of scale.

Production structure, high commercial value and growing uncertainties in the economic and commercial situation in recent years call for greater flexibility in the realm of production. Greater the flexibility, larger is the number of possible alternative plans which leads to increased complexity of planning problem. Complexity and staggering amount of data involvement makes computer assistance mandatory. A computerised production planning can be categorised into following types :

(i) Mid-term planning

(ii) Short-term planning

The mid-term planning problem calls for the capability of capacity assesment in the face of changing market patterns, the determination of new configuration of existing plant to accomodate unfamilar products and the study of possible plant extensions. It is not concerned with details of day-to-day production. On the other hand, in the short-term planning, many day-to-day details are considered. Unlike mid-term planning, here planner does not have a freedom to work with many configuration for

each product. This short-term planning may be thought to be made up of four steps:

(i) generating different batch sequences that meet production targets,

(ii) selecting a sequence which gives the most favourable value of an appropriate objective function,

(iii) preparing day-to-day schedule for the selected sequence keeping in view various constraints and finally,

(iv) to determine the total implementation cost of the best schedule generated .

Such computerised production planning system, capable of solving short-term planning problem in the batch chemical industry can be of enormous help to the planner.

## 1.2 LITERATURE SURVEY :

An extensive literature Conway etal ( 1967 ), Baker (1974), Coffman (1978), Lawler et al (1982), Lenstra, Rinooy Kan ( 1983 ) is available on the sequencing of job-shop and flow-shop problems of the type typically found in the mechanical industries. However very little attention has been paid to problems typical of those found in the

batch chemical industry. A few references are available which describe algorithms developed for very simplified problems.

The simple problem of determining the sequence in which products should be produced to meet specified requirements in minimum time, where no intermediate storage is available, is often relevant to batch chemical production. This is dealt extensively by Suhami and Mah-(1981) and Rippin (1981).Kargaonker (1979) considered sequencing a number of products through a series of equipment items where the production rates are high. A complete enumeration strategy to generate different batch sequences for the set of products, where more than one manufacturing route through the plant is available, was suggested by Egli and Rippin (1981). Rippin has also mentioned that Groeflin (1977) used an implicit enumeration for problems with special structures.

Beside this, considerable amount of work in the fields of computer-aided design and operation of batch chemical plants is attributed to Rippin (1983a, 1983b). In the review paper ( Rippin-1983a), the status of computer-aided methods for design and operation of batch plants with single and multi-product has been surveyed. In the another

paper, Rippin (1983b) has presented a procedure for classifying the structure of batch-processing problems. Joglekar and Reklaitis (1982) have reported the design of a dynamic simulator for batch oriented processes. However, none of these analysis are sufficient to provide significant help for the product manager in typical day-to-day planning problem in multi-product batch chemical plants.

A scheduling algorithm specifically suitable for the needs of the batch process chemical industry has been developed by Chokshi (1984). Based on this algorithm, a computerised scheduler is developed which permits equipment constraints, utility constraints and precedence requirements of the process tasks and schedules batches of the specified products. It is also capable of handling situations of plant shutdowns, equipment failures, raw material non-availability, processing time etc.

## 1.3 PRESENT WORK:

The present work concentrates on the first, second and fourth steps of the short-term planning problem mentioned in the section 1.1. Efforts are directed towards the development of an user friendly, general purpose production planning system specific to the needs of the chemical industry. This computerised system interlinked with the

scheduler developed by Chokshi(1984), is made flexible enough to handle the various objectives and the general cost evaluation schemes of the planner. Various methods are suggested to get good, better and best solution with respect to the above objective. Detailed time schedule of all the batches manufactured and the detailed cost of implementation of the above schedule is also prepared.

## 1.4. THESIS LAYOUT :

Chapter two describes elements which are relevant to the short term planning problem of batch chemical industry. Chapter three presents various techniques that are used in the design of the sequencer. In Chapter four computer program has been discussed keeping in mind the requirements of a user. Concluding fifth chapter briefly describes possible extension that can be incorporated in the sequencer.

# CHAPTER 2

# PROBLEM DESCRIPTION

In a multi-product batch chemical plant where only one route is specified for each product, sequencing problem consists of determination of the sequence in which a set of products should be produced, so that a specified objective, such as time to fulfill all product requirements, penalties for late deliveries, or total implementation cost of the schedule etc. is optimised. This section focusses attention on various elements of short-term planning, in general, in the context of batch chemical industry and the framework in which problem will be structured.

## 2.1 PROBLEM SPECIFICATION:

The data items that are required and the characteristics of various elements are described below.

### 2.1.1 PROCESS TASK:

A process task is an identifiable operation ( or a group of operations) carried out on a specified chemical component ( or a mixture of components ). A sequence of different process tasks yields a batch of

product by undergoing desired transformation in the raw material. This task sequence is assumed to be well defined and this imposes logical constraints. Besides precedence constraints, a process task is characterised by

(i) Mode of production i.e. batch, semi-batch or semi-continuous

(ii) Time requirement for its completion :

Processing time varies with the batch size.

(iii) Raw material requirements of each task and type:
Here assumption is made that all the raw materials that are required for the batch are procured in the beginning of the planning period. In reality, different schedule for material purchase imposes additional constraint on the production planning.

(iv) Utility demands:
In plant, availability of various utilities may not allow simultaneous operation of those process tasks which place heavy demands on the resources. Thus utility requirements for a process taks may be come deciding factor in positioning it on time-scale.

Steam, electricity, refrigation etc. are examples of utilities that may influence scheduling decisions. Depending upon the nature of process, batch-size may affect utility requirements. For certain process tasks, by lengthening the process tasks it may be possible to reduce the rate of utility requirements without deterioration in product quality. Such process tasks could be of help in lessening utility requirements during peak demand periods.

(v) Chemical stability :

Product stability problem is perhaps unique to chemical and metallurgical industries that has to be considered while scheduling the products . If the intermediate material is stable it can remain in the equipment until the next equipment item is ready to recieve it. Thus a task which is stable on completion can be started independently of the availibility of the suceeding item. For a task which is unstable on competion or a series of such tasks the starting time will bedetermined

by the availability of the suceeding items.

2.1.2 EQUIPMENT ITEMS:

Equipment items are the problem elements for batch mode production planning. Total number of equipment items is assumed to be fixed for scheduling. An equipment item can be used by one or more process tasks. Processing time is dependent upon the nature of the process task, whereas cleaning and setup time once processing over are dependent on the incoming and outgoing products. Also a scheduler should be flexible enough to take into account equipment breakdowns.

2.1.3 STOCK HOLDING:

Stock holding costs play an important role in assessing the acceptability of a proposed plan. For each product, information regarding the initial stock level, the minimum level of stock, and the buffer stock are stored. The maximum permitted stock level is not considered. Raw material stock levels are not considered in the planning process, may be treated as a seperate problem.

2.1.4 PLANNING AND SALES DATA :

(i) Available production time:

The starting and finishing times and dates

of the planning period must be specified together with regular working pattern adopted during this period and any shut down period. All the batches should be completed latest by the finishing time of the planning period.

(ii) Sales data:

All customer orders must be complied during the planning period. Delivery date forms the basis for the establishment of the time table for the production processes. All the deliveries are made from the stock at hand, upto the buffer level. Urgent deliveries below buffer level are allowed only with penalty. Partial deliveries are also permited.

## 2.2. SCHEDULE EVALUATION :

In this section various measures to evaluate the different schedules are discussed. The approach is to identify a large number of measures which singly or jointly cover goals of different organisations. The emphasis is on the fact that various organisation may have different criteria to evaluate a schedule, and the program should be

capable of handling large number of such users. Following are some of the criteria commonly used:

(i) to minimise the total penalty due to late deliveries,

(ii) to minimise the total processing time of all batches,

(iii) to find a schedule with a least implementation cost,

(iv) to find a scheduled with least utility or changeover costs etc.

Some of these objective may be in conflict with each other. The present system attempts to overcome all these conflicts by selecting a generalised objective function. The generalised objective function is the cost measure and is defined as the sum of all weighted direct cost which vary with different sequences of batches. These costs are listed below:

- Raw material inventory cost
- Finished goods inventory cost
- Backorder cost
- Change over cost
- Utility cost including manpower cost.

User can varv the relative importance of any cost component by assigning higher or lower weights to these components. Alternatively, one can get all the different components computed and judge their relative importance to select the schedule. Each cost factor and the mechanism by which they are computed are briefly explained below.

### 2.2.1 RAW MATERIAL INVENTORY COST:

In general, inventory is defined as an idle resource of any kind which has economic value. The cost associated in holding these resources is time variant. Typically, inventory cost is made up of the following costs:

- (i) Ordering costs
- (ii) Cost of shortages
  - (a) Cost of backorder
  - (b) Lost sales cost
- (iii) Inventory carrying costs.

Ordering cost is the amount of money ( resources ) spent in getting an item into inventory e.g. cost of placing orders cost of maintaining accounts for these orders etc. On the other hand, cost of shortages arises when there is demand but no item in stock. When stockout occurs there can be two

distinct cases. The backorder case, where the customer is informed that this order is treated as backorder and will be supplied when the item is in stock. The second case occurs when sales are lost. Lastly the inventory carrying costs are costs incurred in maintaining stock which include storage cost, pilferage, blocked capital cost etc.

It is assumed that all the raw material required for the production of set of products are procured in the beginning of the planning period. So the cost associated with raw material shortage and ordering remains same for different sequences. Only component of inventory cost which will vary with different sequences is the blocked capital cost. The blocked capital cost S, is expressed as

$$S = I \times C_j \times \int_0^t x_j(t)\, dt$$

where $t$ = time period for which material is stored,

$x_j(t)$ = on-hand inventory level of item i which is a function of time,

$I$ = Inventory carrying charge expressed in terms of cost per unit time per monetary unit invested in inventory, and

$C_j$ = Unit cost of the item j in inventory.

User has to provide information regarding I and $C_j$ for each raw material.

For each raw material, the amount and date on which it is consumed is found out from the raw material consumption chart developed in the scheduler. Thus the integral part of the above expression is evaluated. The summation of blocked capital costs of all the raw materials gives the total raw-material inventory cost of the schedule.

2.2.2 FINISHED GOODS INVENTORY COST :

Unlike raw material inventory cost, cost of shortages is taken into consideration, while evaluating total finished goods inventory cost as they may be dependent on the schedule. Therefore the status of the product requirement plan and stock holding information of each product plays an important role. The method of computing finished goods inventory cost is breifly explained in the flow chart given in figure 2.

The planner has a choice to select either partial delivery or full delivery of the products ordered. The finished goods inventory cost is computed accordingly.

2.2.3 BACKORDER COST:

Backorder costs are incurred when demand occurs and item is out of stock. Backorder costs are

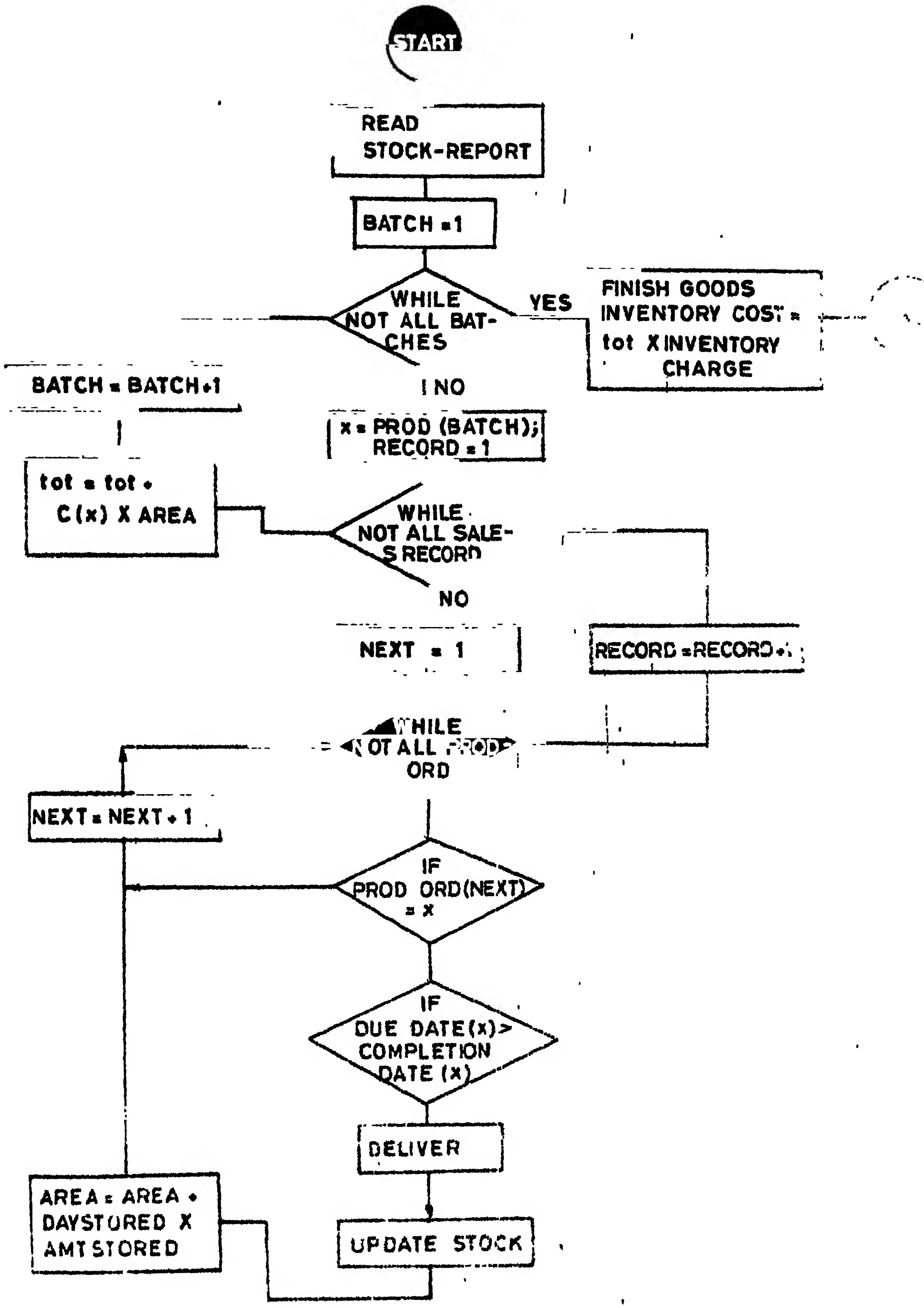


FIG 2 FLOW CHART FOR FINISHED GOODS INVENTORY

inherently extremely difficult to measure since they include such factors as loss of customer's good will, lack of keeping machine idle and cost of notifying a customer that item is not in stock and will be backordered. Backorder costs are made up of fixed costs and variable cost which vary with time, units backlogged and items backlogged. Fixed penalty is paid if any order is backordered. Following are the variable costs.

(i) Variable penalty cost per day backlogged
(ii) Variable penalty cost per unit of item backordered
(iii) Variable penalty cost per article backordered.

In the computerised system, the user can select the backorder policy. Three such policies to compute backorder cost are

(i) fixed cost + variable penalty cost for number of days delayed

(ii) fixed cost + variable penalty cost for number of articles backordered.

(iii ) If partial delivery then
fixed cost + variable penalty cost for number of days delayed + variable penalty for number of units backordered + variable penalty cost for number of articles backordered.

According to the policy chosen for all the customer record if backordered, the backorder cost is calculated. If user's priority is not specified, third policy is treated as default.

### 2.2.4 CHANGEOVER COST:

In a typical batch chemical plant, the products are processed on different equipment modules. Many products use the same equipment at different points of time. Before new product is processed in the equipment, additional cost is incurred in unloading the contents of the previous product, cleaning with water acid or solvent to avoid contamination and finally loading the new batch. These costs may vary with respect to changeover time , or with the properties of incoming and outgoing products. Such costs are termed as changeover costs which obviously depend on the sequence of products. The user may select any one of the costing schemes based on the changeover times or properties of products processed to evaluate the changeover cost.

The total changeover cost for the complete schedule is the sum of all changeover costs for all the equipment.

## 2.2.5 UTILITY COST:

In a batch chemical industry, many utilities such as steam, electricity, refrigration etc. are used frequently. For any time-interval, the total utility consumed by all the process tasks scheduled at that time is constrained by its availability. This utility constraint plays an important role in scheduling of the batches. For different utilities, the cost function of consumption may be similar or different. Based on these cost functions, following cost evaluation schemes are incorporated in the program.

For utilities like steam, electricity, refrigation

(i) Cost based on total consumption
Total consumption per period is found out from the scheduler. Summation of total consumption in the whole planning period when multiplied with utility consumption cost per period, for a utility gives total utility cost of consumption of that utility

(ii) Cost proportional to maximum level of utility consumed

A fixed cost is paid on consumption of utility upto the pre determined level. An additional cost per unit consumed is incurred on consumption above this level

(iii)Cost varying with the time of the day.

Many time, to avoid consumption during peak hours , very high cost is charged.

Besides this, the facility to evaluate manpower cost ( here manpower is treated as utility ) is also provided. Fixed wage is paid for a worker working in regular hours. If he works beyond the regular hours, high additional cost or overtime may be incurred. During manpower crisis, the sequence with least manpower cost may be desirable. The present system facilitates planner to find such schedule. Analogous to this, schedule which gives minimum consumption of critical utility may also be generated.

The summation of all these costs computed according to user's specification, gives the total utility cost which varies with the different sequences of products . In summary Table 1 provides various steps involved in batch sequencing and options available at each step.

TABLE 1

OPTIONS AVAILABLE OF DIFFERENT STEPS IN BATCH SEQUENCING.

| | |
|---|---|
| **1** | **SCHEDULE EVALUATION CRITERIA** |
| 1.1 | Total penalty paid due to late deliveries |
| 1.2 | Total processing time of all the batches |
| 1.3 | Total implementation cost of the schedule generated |
| 1.4 | Total changeover cost |
| 1.5 | Total utility cost |
| **2** | **SEQUENCING TECHNIQUES** |
| 2.1 | Exact Algorithms |
| 2.1.1 | Complete enumeration |
| 2.1.2 | Branch and bound |
| 2.2 | Heuristic Based Algorithms |
| 2.2.1 | Local neighbourhood search |
| 2.2.2 | Non backtrack branch and bound |
| 2.3 | Despatching Rules Based Heuristics |
| 2.3.1 | Processing time |
| 2.3.2 | Max-process |
| 2.3.3 | Minimum critical utility |
| 2.3.4 | Total cost |
| 2.3.5 | Modified- EDD |
| ~~2.3.6~~ | ~~Product grouping~~ |

## 3 COST EVALUATION SCHEMES

3.1 Raw Material Inventory Cost

3.1.1 Blocked capital evaluation

3.2 Finished Goods Inventory Cost

3.2.1 Partial delivery not allowed

3.2.2 Partial delivery allowed

3.3 Backorder Cost

3.3.1 Fixed cost + variable cost/day

3.3.2 Fixed cost + variable cost/ articles backordered

3.3.3 Fixed cost + variable cost/ articles + variable cost/ unit, + variable cost/day

3.4 Change Over Cost

3.4.1 Cost proportional to changeover time

3.4.2 Cost varying with incoming and outgoing product

3.5 Utility Cost

3.4.1 Cost per unit consumed per unit time-interval

3.4.2 Cost varying with the time of the day

3.4.3 Cost proportional to maximum level of the utility consumed

3.4.4 Manpower cost

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The various sequencing techniques will be discussed in the next chapter.

# CHAPTER 3

## SEQUENCING METHODOLOGY

Selecting an optimal sequence and its scheduling, in practice, is a difficult problem. With the increase in the number of batches, utilities, equipments and raw materials, the time to get such a sequence will grow at a very fast rate. Thus in practice a trade-off has to be made between the closeness to the optimal sequence and the time and cost of getting such a sequence. The approach followed here is to provide an aid to the decision maker in selecting a method to solve his specific problem under the time and cost constraints. Hence, unlike the classical approach, no attempt is made to give an algorithm to obtain the optimal or sub optimal solution. Utility of a specific method, whether exact or heuristic will be dependent to a large extent on the problem environment, and have the decision-maker has to experiment to get methods suitable for his specific situations.

A variety of exact and heuristic approaches are in-built in the system in such a way that a decision maker can interact with the system and, with little effort, can select a method which will suit his problem situation.

In this, it should be noted that no attempt is made to suggest a specific method . The sequencing methods are divided into three catagories namely exact algorithm, heuristic based algorithm and despatching rules based heuristic . For all the above mentioned methods, that are explained in detail in the forthcoming sections, the user has to specify.

(i) schedule evaluation criteria
(ii) starting and finishing time and date of planning period
(iii) number of batches required
(iv) product code and batch size of those batches
(v) appropriate cost evaluation schemes and weights for each cost factor

The user can interact with the system to select one or more than one method to generate the sequence. Certain amount of experimentation is suggested so that user can make right choice of the method.

## 3.1 EXACT ALGORITHM:

The algorithm which guarantees optimal solution in finite number of steps is called as an exact algorithm. Enumeration is one type of exact algorithm which can handle many combinatorial problems like sequencing, Travelling salesman problem etc. Explicit enumeration evaluates all

the mutually exclusive combinations that exist for a set of batches one by one. High computational cost and memory storage makes this method undesirable for the case where number of batches is large . In implicit enumeration some inferior solutions are eliminated in a intelligent manner and there by computing time is reduced.

### 3.1.1 COMPLETE EMUMERATION:

All the permutations of the schedules are generated one by one by using a stack. One complete sequence is selected, the scheduler is called to find the objective function value. On completion of all the permutation schedules, with minimum cost is selected. With the increase in number of batches, the number of sequences to be generated increases, consequently computational cost. So this method is suitable for small number of batches.

### 3.1.2 BRANCH AND BOUND TECHNIQUE:

When the number of batches is large and optimal solution is desirable, the technique of 'branch and bound ' is best suggested. This technique Baker (1974), Coffman (1974),is based on the idea of partitioning the feasible solution sets into subsets by a process of branch-ing and eliminating non-optimal solutions by bounding this subset. If the lower bound calculated for each subset is

smaller than the best objective function value of the incumbent solution also known as upper bound and if the subset with lower bound is feasible further branching from this subset is stopped. This is known as fathoming . If the above condition is false such subsets are excluded from further partitioning. This is known as pruning. The partitioning continues until a feasible solution is found such that its value is not greater than the lower bound for any subset. The algorithm terminates when all the subsets are either pruned or fathomed. The curtailment of maximum number of branches very much depends on the lower bounds of the subset and the starting solution.

Any branch and bound technique is characterised by various strategies briefly explained below:

(i) Bounding Strategy :

The upper bound (UB) can be calculated by solving the problem by any heuristics based algorithms or heuristics described in the next section of this chapter . Let the kth candidate problem be denoted by $p^k$. Let S denotes the set which contains complete sequence .

For problem $p^k$,

$\sigma_k$ denotes the set containing elements which contains partial permutation schedules corresponding the problem $p^k$

$\sigma_k'$ denotes the set containing elements not in $\sigma_k$

LB be the lower bound for candidate problem $p_k$

Two bounding strategies are proposed, user may select any one of them according to amount of computing time or cost he is willing to spend.

(a) LB for $p^k$, LB = L1= total objective function partial schedule $\sigma_k$

(b) LB for $p^k$, LB = L1+L2

where where L2 = $\Sigma z'_k$, for all elements in $\sigma_k'$

and $z'_k$ = objective function value of a element in $\sigma_k'$

For all the elements in $\sigma_k'$, the scheduler is run to find out $z'_k$, when contribution due to finished goods inventory cost put equal to zero. The above step is justified by observation that all cost components of objective function except finished goods inventory cost do not increase with delay in completion date of the product. By addition of L2 to L1, this bound becomes stronger.

User can incorporate any other bounding strategy suitable for his requirement.

(ii) Pruning Strategy:

We prun any intermediate problem $p^k$, if lower bound LB is greater than the value of the objective function of best feasible solution obtained upto that stage.

For candidate problem $p^k$, $LB > UB$

(iii) Branching Strategy:

If a candidate problem $p^k$ is neither fathomed nor pruned, it is used for subsequent branching. To perform branching at a candidate problem $p^k$, we select the product which is not present in subset $\sigma_k$ of $p^k$ and has maximum $z_k'$ of all the elements in $\sigma_k'$ of $p^k$.

User can incorporate any other branching strategy.

(iv) Fathoming Strategy:

We fathom any subset $\sigma_k$ if it is a complete permutation schedule i.e. $\sigma_k \sim S$

(v) Searching Strategy:

As far as searching strategy is concerned, depth first search is employed because of the ease of implementation and less storage requirements.

The flow chart for the above algorithm is shown in figure 3.

User choices for branch and bound technique:

(i) Starting sequence

(ii) Upper bound

(iii) Bounding strategy

(a) LB = L1 = Objective function value

(b) LB = L1+L2

(iv) Branching strategy

(a) Maximum of objective function value of elements in $\sigma_k'$

(b) Random selection.

## 3.2 HEURISTIC BASED ALGORITHM :

Many a times a good sub-optimal solution is more desirable than optimal solution due to lesser computational cost. These algorithms, to be described below, are based on standard rules such as non-backtracking, pairwise exchange Coffman (1976), may give reasonably good solutions. The user is provided with two such methods. These methods are very suitable for the problem with large number of batches.

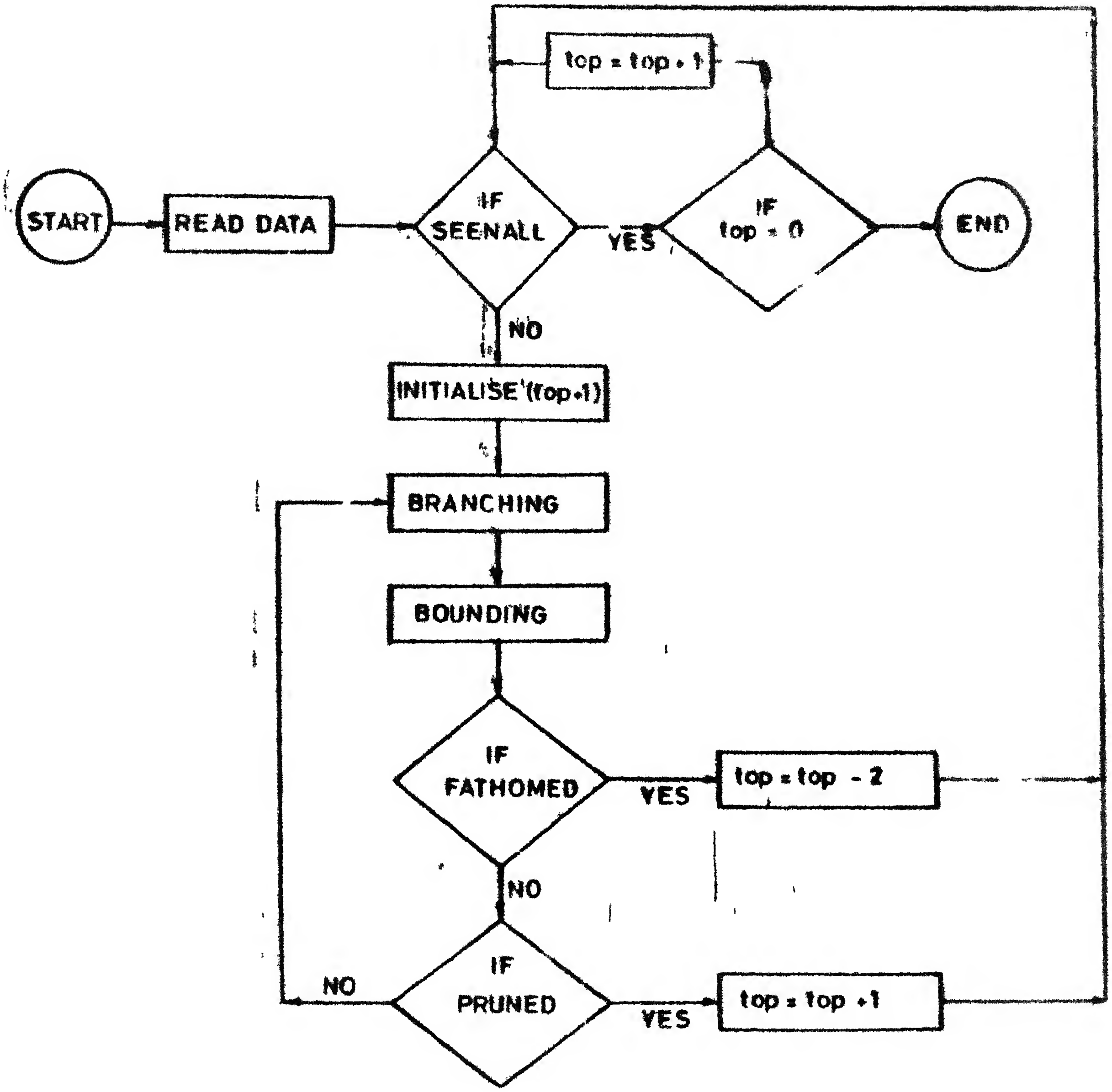



FIG. 3 FLOW CHART FOR BRANCH AND BOUND TECHNIQUE

### 3.2.1 NON-BACKTRACKING BRANCH AND BOUND:

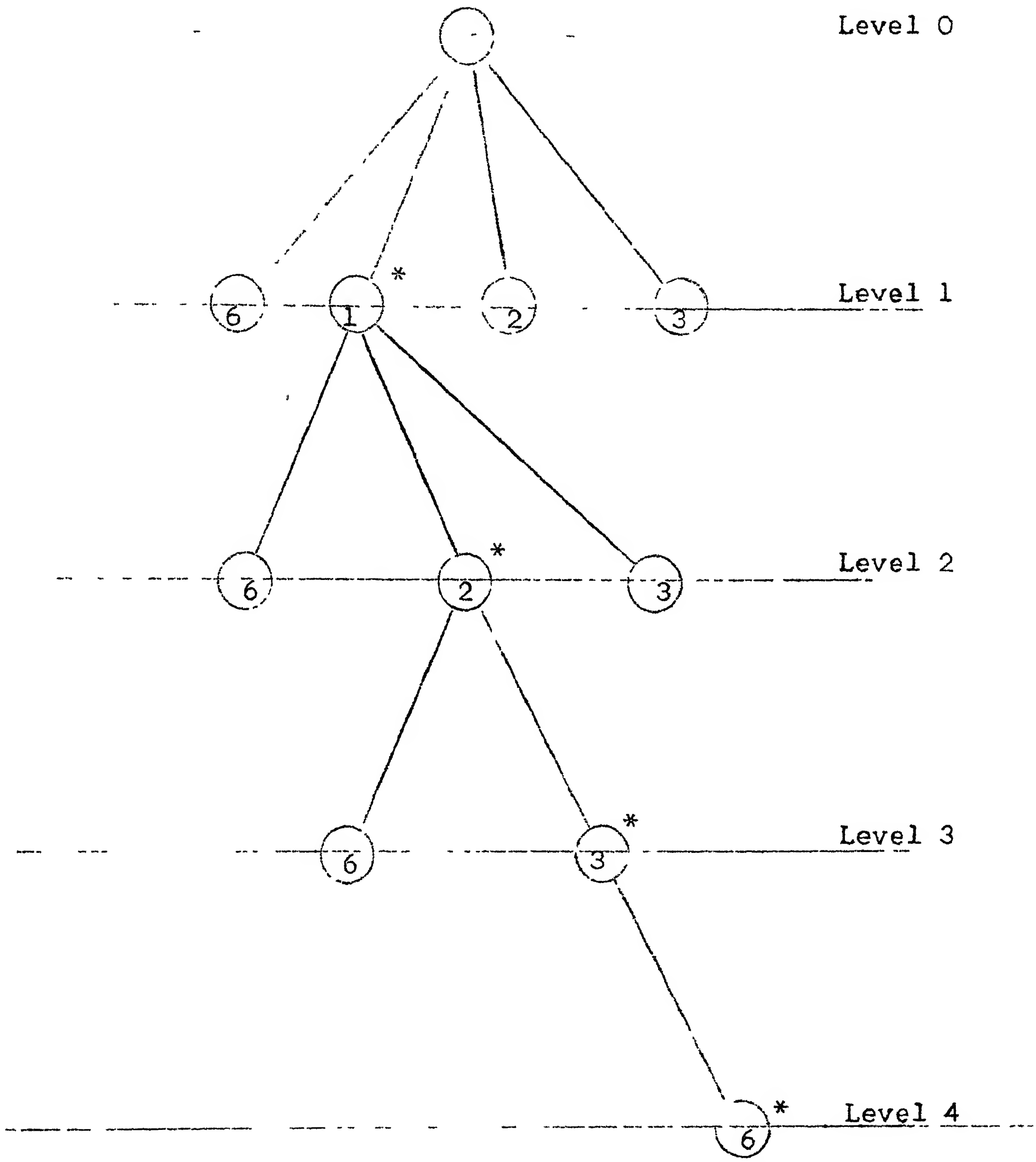
This algorithm is similar to branch and bound where backtrack is avoided. Due to non-backtracking, storage requirement is much less. At each level, all the possible nodes are generated and information regarding their LB is stored. The smallest LB among these modes is selected and its position in the sequence is fixed. Thus this product is not considered for next higher level. The process is terminated when a feasible solution is obtained. Thus backtrack is avoided but at the same time lower bounds are used to select the incoming product in the sequence.

Above algorithm is explained by a sample problem in figure 4.

No choice specific to this method is provided for the user. But user may incorporate some other strategy.

### 3.2.2 LOCAL NEIGHBOURHOOD SEARCH:

The algorithm is based on the idea of trial and error. It starts with a feasible solution i.e. a complete sequence, tries to improve the solution by making small changes in the neighbourhood of the solution set. In a complete sequence, the position of different elements are interchanged one at a time if this results in improvement




1-2-3-6 is the
complete sequence

Fig. 4 An example of Non-backtracking branch and bound technique.

in the objective function value, the present sequence is retained . User can specify the termination strategy of the process. It may be continued until no further improvement in solution is possible or after specified number of pairwise interchanges. This serves as a very good starting solution for the branch and bound technique.

User's Choice:

(i) Initial starting sequence

(ii) Process termination criteria

(a) no further improvement in objective

(b) number of pairwise exchanges to be done.

## 3.3 DESPATCHING RULES BASED HEURISTICS:

Heuristics are ' thumb rules ' which exploits the special characteristics of the problem and tries to give good feasible solution without a formal guarantee of performance. The performance of these rules varies drastically with different objective functions. The given planning system exploits the complex structure of the planning problem which is dependent on the various elements like, utilities, equipments, raw materials and finished good stocks etc. On the basis of under given priority rules a complete sequence is generated.

### 3.3.1 PROCESSING TIME :

For any sequence specified by the user, ~~also~~ the present method can arrange the products in the sequence ascending or descending ( user's spefification ) order of their processing time.

### 3.3.2 MINIMUM CRITICAL UTILITY:

User has to specify the critical utility code and the ordering scheme. On the basis of this specified ordering scheme i.e. increasing/ decreasing order, the product which consumes minimum of specified critical utility is arranged accordingly.

### 3.3.3 MAXI~~MUM~~ PROCESS:

The product with maximum number of process tasks is given highest priority and is started first, the process is repeated with the remaining product .

### 3.3.4 TOTAL COST:

For the number of batches and products specified by the user, the scheduler is run for each product individually and according to his specification the total cost i.e. the value of cost function is computed. Here the user can

specify ascending or descending order of the cost for sequencing. The products are arranged accordingly.

3.3.5 MODIFIED-EDD:

Earliest due date (EDD) is the standard despatching rule Baker (1974), Coffman (1974) used for scheduling. Here idea of earliest due date is modified where the earliest date on which the product goes below the buffer level is found out from the stock holding information and sales-order data. Product to be produced are arranged in increasing order of their modified due date. The idea is to minimise the backorder costs to some extent.

The block diagram for the chemical batch sequencer is shown in figure 5. The various options available pertaining to various sequencing techniques are shown in Table 2.

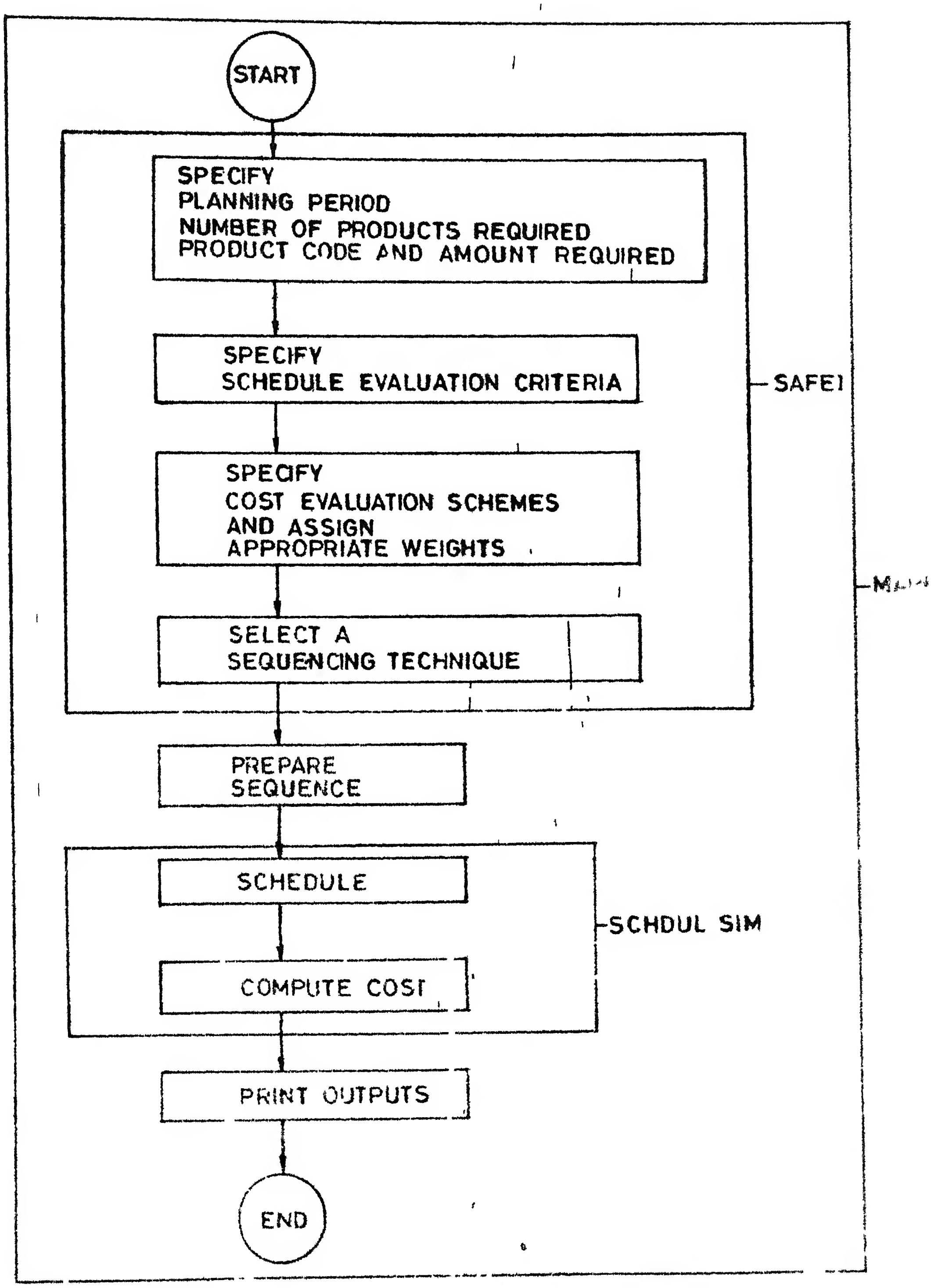



FIG 6 BLOCK DIAGRAM FOR THE BATCH SEQUENCER

TABLE 2

USER'S OPTIONS FOR SEQUENCING TECHNIQUES

| | |
|---|---|
| 1 | SEQUENCING TECHNIQUES |
| 1.1 | Complete Enumeration: |
| 1.2 | Branch and bound technique: |
| 1.2.1 | Starting sequence |
| 1.2.2 | Upperbound |
| 1.2.3 | Bounding strategy |
| | (a) LB = L1 |
| | (b) LB = L1+L2. |
| 1.2.4 | Branching strategy |
| | (a) Minimum ($z_k'$) for all elements in $\sigma_k'$ |
| | (b) Random selection |
| 1.3 | Non backtracking branch and bound: |
| 1.4 | Local neighbourhood search : |
| 1.4.1 | Initial starting sequence |
| 1.4.2 | Process termination criteria |
| | (a) Until no further improvement is possible |
| | (b) Number of pairwise exchanges to be done |

Contd... Table 2.

1.5 Processing-Time:

1.5.1 Arranging order

(a ) ascending

(b) descending

1.6 Minimum-Critical Utility:

1.6.1 Critical utility code

1.6.2 Arranging order

(a) ascending

(b) descending

1.7 Max~~imum~~ Process:

1.8 Total-Cost :

1.8.1 Arranging order

(a) ascending

(b) descending

1.9 Modified-EDD:

# CHAPTER 4

# USER'S MANUAL

Based on the algorithms discussed in previous chapter, two computer programmes, MAIN.SIM and SCHDUL.SIM have been developed. These two programmes can be used to prepare a detailed schedule for a batch chemical plant. Both the programmes are written in SIMULA language for DECSYSTEM - 10, Object codes MAIN,REL, SCHDUL. REL and SCHDUL.ATR, are generated using SIMULA compiler ( Version 3 ). Execution the programs require 3rd version of SIMULA runtime system.

Besides several utility procedures, a utility package SAFEI ( Version 4 ) is used by the program MAIN.SIM. SAFEI requires a file name SAFEIO.ENG, which is also supplied along with MAIN.SIM and SCHDUL.SIM. SAFEI and other utility procedures should be available in the library LIBSIM on the SYS : area of the system.

## 4.1 DATA INPUT:

Some help information regarding various facilities that are provided to the user are displayed on the screen after the following command: EXECUTE MAIN.REL. After this, various questions are prompted on the terminal screen and

user is required to type in the answers. For most of the questions, that are prompted, limited help information is also supplied on user's request at run time. To get help information, on any question, user has to type in '?' , in answer to the question. Limited validity following an error message. A typical dialogue that takes place at run time is reproduced in appendix A. Appendix B lists the validity checks that are provided for.

Following nine disk file are required for program execution .

- INPUT
- PROF.MAP
- PROFS.ALT
- CLEAN.TIM
- TEXT.DAT
- STOCK.RPT
- COST.DAT
- ORDER. DAT
- VALUE.

Help file, PROG.HLP is also réquired for execution. Helpful instructions on preparation of the data files are given in Section 4.

## 4.2 PROGRAM EXECUTION:

Both the programs are interlinked, and a single execution command (EXE MAIN.REL) activates both MAIN.SIM and SCHDUL.SIM. Initially, availability of data files, INPUT , PROF.MAP etc. on disk area of the user is checked. If, any one of the files are not available, then following error message is flashed on the screen and execution is cancelled.

'?... ERROR ..... ERROR ..?

DATA file; ----- is not available on the disk.

Execution is deleted.

During dialogue with user, through SAFEI system, appropriate error message is issued when ever validity check for an answer fails. User is advised to type answers carefully in order to avoid errors caused by non-integer answers.

## 4.3 OUTPUT :

After the execution is over, results are stored on a disk file OUTPUT, which has line printer orientation.

GANTT charts and utility utilisation charts are prepared only after confirmation from user is received.

User's choice is asked for in following manner:

" If GANTT charts are to be prepared, then type 0
Else type any other character "

Similar message is asked for choice regarding utility consumption charts. Disk file BATCH.STR contains schedules that are prepared for all product batches. PROCESS .STR stores occupancy vector information for each of the quipment ( processor ) in the plant. UTLTY.STR is used to store loading vector for each of the utilities. TOTCOS gives detailed cost of implementation of the schedule generated. OUTPUT 2 gives detailed report of the planning problem undertaken.

## 4.4 PREPARING DATA FILES :

Preparation of five data files, namely INPUT, PROF. MAP, PROFS, ALT and TEXT.DAT are described in earlier work Chokshi (1984). Preparation of other disk files is explained under.

### 4.4.1 CLEAN.TIM:

This data file supplies cleaning and product change-over or set up times for the equipment items that are used. Cleaning and changeover times may be dependent on product sequences a list of these times should also indicate product order.

Record length for this data file is 132 spaces. The data items for a single equipment item can be spread over several lines.

First line for an equipment item should contain a code in the beginning. A character U followed by code number of the equipment, makes up the code. Next, an integer should be given, which indicates number of data records that are supplied for the equipment. A data record consists of 4 data items. Code number of product for which the equipment item was used previously,code nnmber of product to which the equipment is about to be switched over, cleaning and setup time and changeover cost .

Table 3 shows cleaning and setup time and changeover cost information for equipmert. No.5. Corrosponding entries in data file are:

TABLE 3

AN EXAMPLE OF CLEANING AND CHANGEOVER TIMES AND COSTS (CLEAN. TIM)

| Equipment No | Product From | Product To | Cleaning and change over time, hrs. | Changeover cost, Rs. |
|---|---|---|---|---|
| U5 | - | 2 | 1.0 | 5.00 |
| | - | 3 | 0.5 | 9.00 |
| | - | 5 | 1.2 | 11.00 |
| | 2 | 3 | 0.75 | 15.50 |
| | 2 | 2 | 3.5 | 17.50 |
| | 2 | 5 | 1.25 | 12.50 |
| | 3 | 2 | 4.0 | 31.00 |
| | 3 | 3 | 0.5 | 4.25 |
| | 3 | 5 | 1.0 | 5.50 |
| | 5 | 2 | 2.0 | 17.50 |
| | 5 | 3 | 4.25 | 17.00 |
| | 5 | 5 | 1.25 | 21.00 |

### 4.3.2 COST.DAT:

This disk file supplies different details of each cost component of the cost function. Program SCHDUL.SIM reads information related cost components from this data file. Record length for each line is 132 spaces. All the cost components used are of real type.

First line contains, changeover cost per unit time for each processor. This cost is different from changeover cost i.e, dependent on the incoming and outgoing product, which is provided in the disk file CLEAN.TIM.

Next ( 1+3 ( number of utilities )) lines, contain details of various costs, corrosponding to three cost evaluation schemes. The cost proportional to total utility consumed per time-interval, for each utility, that is used in first scheme is provided in the second line of this file. Next three lines, for the 3 utilities used, gives information regarding scheme : 2. Each line contain three data items.

(i) Permissible level i.e. the level upto which fixed cost is incurred. On consumption above this level extra cost per unit consumed is incurred.

(ii) Fixed cost.

(iii) Variable cost per unit of utility consumed above permissible level.

For scheme : 3, where cost is proportional to time of the day, information regarding time range and cost corresponding to these ranges are furnished. For each utility, having such dependency discretized graph, cost versus time of the day, should be prepared. Figure 6a , shows a discretized graph for such utilities. Entires on the line are values of distinct co-ordinate pairs from the above -mentioned graph. For example, line corrosponding to figure 6a, reads:

5 6 0.30 10 1.20 17 2.00 20 0.80 24 0.40

The first item of this line is the number of such discrete points. Number of such discrete points should not exceed 10. User is asked to provide integer type data corrosponding to the coordinate of the time of the day. In the case when cost of the utility does not vary with the time of the day a constant cost can be provided (Ref. to figure 6b ), as

1 0.9

In next line of the data file, for each raw material, cost of raw-material/unit is provided information regarding backorder and finished goods inventory are provided in next four lines .

(i) Variable penalty to be paid if any article is backordered.

(ii) Variable penalty per day for each product.

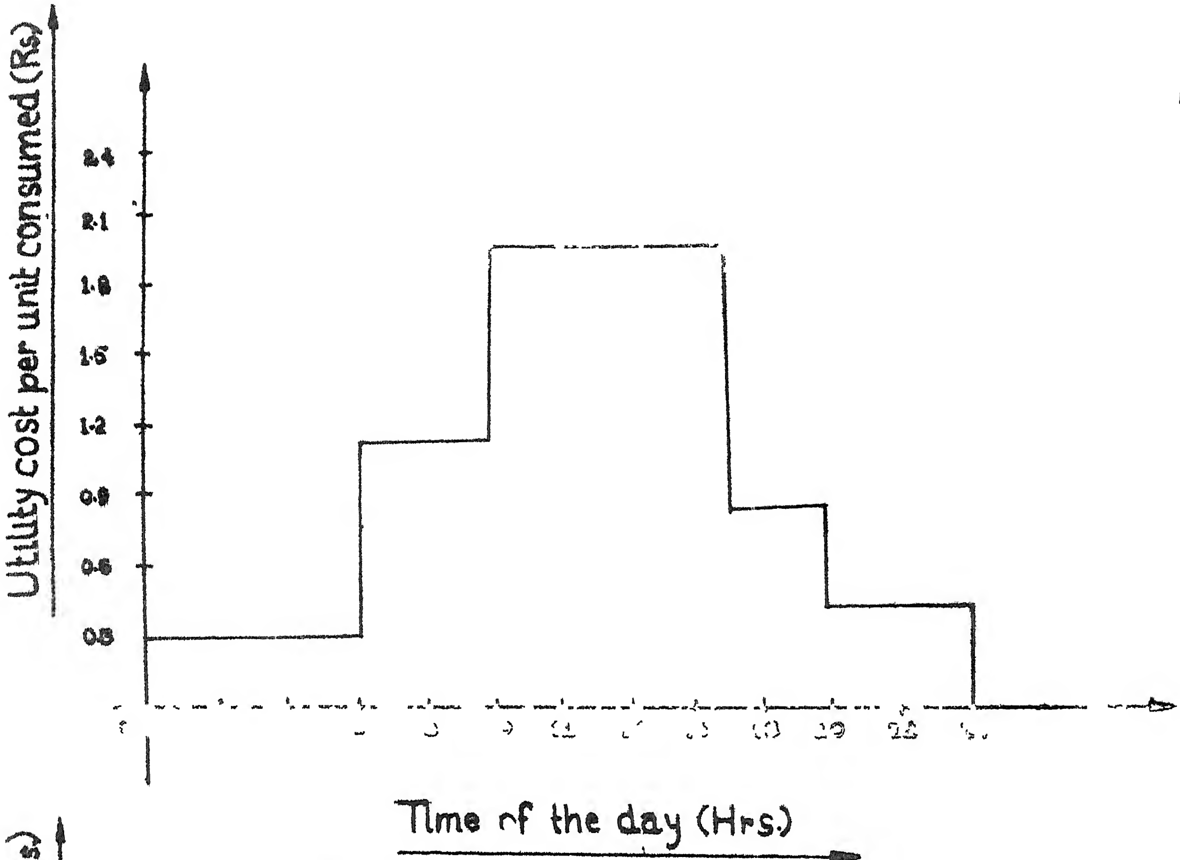



Fig 6(a) Utility cost vs.
Time of the day

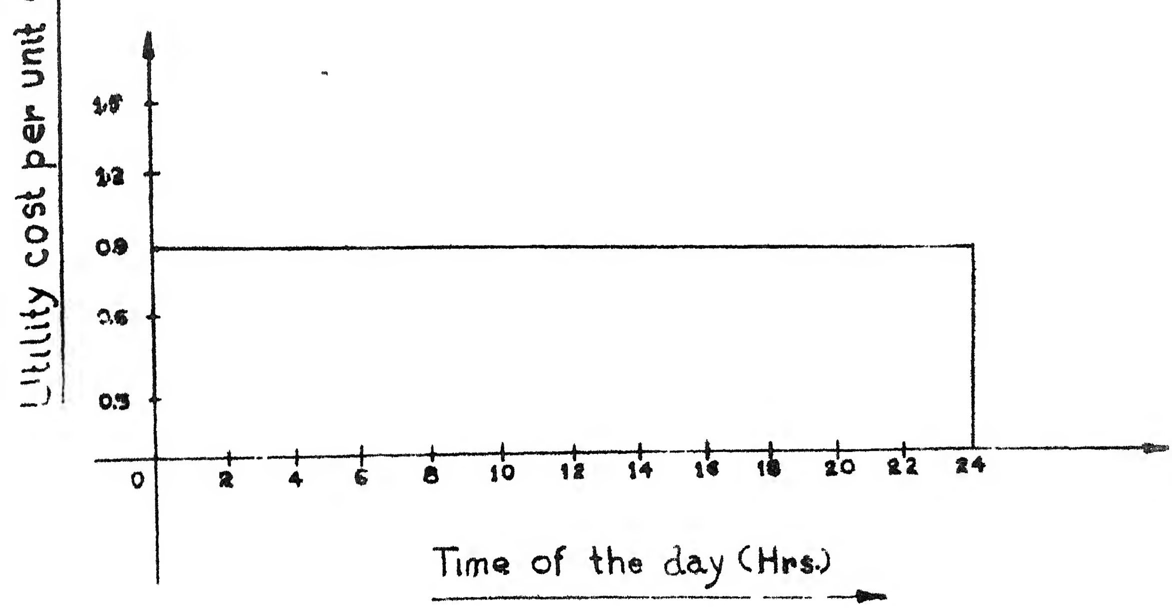



Fig 6(b) Utility cost constant with
Time of the day

(iii) For each product, variable penalty cost per unit backordered is given .

(iv) Fixed penalty cost, is backordered and Inventory carrying charge is given .

Effictively 14 lines are required for 18 processors, 3 utility 10 raw materials and 10 products.

4.4.3 STOCK.RPT :

This file contains stock holding information about various products in stock. Each record length is fixed to 132 spaces.

Each record consists of 4 items, e.g. product code, Initial stock level in Kg., Buffer level in Kg. and manufacturing cost of the product. The first is integer item while other three items are real in nature. For 4 products to be produced, stock holding information is given in Table 4.

TABLE 4

AN EXAMPLE OF STOCK HOLDING INFORMATION ( STOCK.RPT )

| Product Code | Initial level, in Kg. | Buffer level, in Kg. | Manufacturing costs Rs. |
|---|---|---|---|
| 6 | 250.00 | 150.00 | 51.00 |
| 1 | 500.00 | 350.00 | 12.00 |
| 2 | 100.00 | 150.00 | 21.00 |
| 3 | 125.00 | 125.00 | 11.00 |

### 4.3.4 ORDER.DAT :

This data file consists of the sales order for various customers. Each record is of length of 132 spaces. Each order record consists of following items.

- Customer-code  Text type of size 4 character,
- Due date of delivery  day and month, both integer type
- Number of products ordered  integer type

For each product ordered

- Product code  integer type
- Quantity ordered real type

Table 5 gives a typical example of this data file.

### 4.3.5 VALUE:

This data file is not an input file, but is created during execution. For each product, various information regarding processing time, number of process tasks, etc. are stored, which are used by the various algorithms.For each product to be produced, SCHDUL. SIM is called and above information regarding its processing time, number of process tasks present, utility requirements of the product and the total implementation cost of each product are stored.

TABLE 5

AN EXAMPLE OF SALES ORDER (ORDER.DAT)

| Customer Code | Due Date | | No. of product ordered | Product Code | Amoutn orderec in Kg. |
|---|---|---|---|---|---|
| | Day | Month | | | |
| BXDM | 30 | 6 | 1 | 1 | 150.00 |
| XXZZ | 1 | 7 | 1 | 6 | 150.00 |
| MTSS | 9 | 7 | 1 | 6 | 105.00 |
| RTO1 | 11 | 7 | 1 | 3 | 200.00 |

## 4.5 SAMPLE PROBLEM:

We shall demonstrate the methodology developed so far using a test problem. The objective of running the test problem is to show that how a decision maker can interactively use the developed program

(a) to identify the importance of different weight on different cost components and select a suitable objective function,

(b) to identify the best method for his problem situation.

For all this experimentation, the following input-data will not change:

- number of utilities used,
- number of equipments used,
- number of sales orders,
- duration ofpplanning period, and
- cost evaluation schemes.

Three such experiments are done in the following manner

(a) Decision maker can select various weightages combination and for each of the combination for various sequencing techniques are computed. Test problem is run on 7 different combination and results are shown in table 6 election of the weight combination is entirely dependent on the decision maker.

(b) For a specified objective (weightages fixed) the test problem is run by varying the number of batches for each of the techniques. Results are shown in table 7. This will provide information about the time which may be needed for different size problems.

(c) For a specified objective and specified problem the solution are computed by different method and relative cost as well as the CPU timeis obtained. This can be effectively used to select the most appropriate method for the problem situation under consideration.

It may be noted that usually in a real life situation while the problem data will vary, the nature of the problem and objective will remain the same and hence this experimentati may have to be done only once and when there aremajor changes i the objective of the scheduling or in problem structure.

TABLE 9: RESULTS OF EXPERIMENT (A)

Number of Batches: 4

Products Produced: (1,2,5,6)

| ch & Bound | | Non-backtracking Branch and Bound | | | Local neighbourhood search | | | Min Critical Utility (Ascending) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cost (Rs) | CPU (Min) | Sequence | Cost (Rs.) | CPU (min) | Sequence | Cost (Rs.) | CPU (min) | Sequence | Cost (Rs) | CPU (min) |
| 43298 | 02.53 | 5-2-6-1 | 44284 | 00.27 | 1-5-2-6 | 43298 | 00.33 | 6-5-2-1 | 44967 | 00.04 |
| 1363 | 01.12 | 5-1-6-2 | 1675 | 00.19 | 1-5-6-2 | 1363 | 00.34 | 6-5-2-1 | 17520 | 00.05 |
| 308 | 01.38 | 1-5-2-6 | 337 | 00.18 | 1-6-5-2 | 326 | 00.23 | 6-5-2-1 | 39700 | 00.04 |
| 5829 | 02.32 | 1-5-2-6 | 6151 | 00.18 | 1-5-2-6 | 6151 | 00.49 | 6-5-2-1 | 7229 | 00.04 |
| 35272 | 02.52 | 5-2-1-6 | 36092 | 00.20 | 1-5-2-6 | 35272 | 00.49 | 6-5-2-1 | 35545 | 00.05 |
| 1409 | 01.25 | 5-1-6-2 | 1723 | 00.21 | 1-5-6-2 | 1409 | 00.47 | 6-5-2-1 | 1789 | 00.04 |
| 56571 | 02.46 | 5-6-1-2 | 62403 | 00.23 | 1-5-6-2 | 56571 | 00.49 | 6-5-2-1 | 60791 | 00.05 |

55

TABLE: 7 RESULTS OF EXPERIMENT (B)

Objectives: Minimise total implementation cost of the schedule

Weightages: 1 1 1 1 1

| Non-backtracking B&B | | | Local Neighbourhood Search | | | Min Critical Utili -- - (Ascending | |
|---|---|---|---|---|---|---|---|
| Sequence | Cost (Rs.) | CPU (min.) | Sequence | Cost (Rs.) | CPU (min.) | Sequence | Cost (Rs.) |
| 5-7-4-3-2-1 | 117270 | 00.39 | 4-1-2-5-7-3 | 109141 | 01.17 | 3-7-5-4-2-1 | 127410 |
| 4-7-2-3-1 | 119321 | 00.28 | 1-4-7-2-3 | 104984 | 00.56 | 7-5-4-2-1 | 110261 |
| 5-2-6-1 | 44384 | 00.21 | 1-5-2-6 | 43298 | 00.33 | 6-5-2-1 | 44967 |
| 5-2-1 | 39000 | 00.09 | 1-5-2 | 37544 | 00.13 | 5-2-1 | 39000 |

TABLE 8: RESULTS OF EXPERIMENT (C)

Objective: Minimise total implementation cost of the Schedule Weightage given to the five cost components: 1 1 1 1 1

Number of batches: 6

Products used: ( 1,2,3,4,5,7,)

| Sequencing Technique | Sequence | Cost(Rs.) | % ERROR | CPU(mins) |
|---|---|---|---|---|
| Branch & Bound | 1-4-2-5-7-3 | 109141 | 0 | 20.11 |
| Non-backtracking B&B | 5-7-4-3-2-1 | 117271 | 7.45 | 00.39 |
| Local neighbourhood search | 4-1-2-5-7-3 | 109141 | 0 | 01.17 |
| Minimum Critical Utility(Ascending) | 3-7-5-4-2-1 | 127410 | 16.73 | 00.05 |
| (Descending) | 2-1-4-5-7-3 | 122352 | 12.10 | 00.05 |
| Processing time (Ascending) | 1-2-4-5-7-3 | 117093 | 7.28 | 00.05 |
| Descending | 3-7-5-4-2-1 | 127410 | 16.73 | 00.05 |
| Max-process | 3-7-5-4-1-2 | 129304 | 18.48 | 00.05 |
| Modified-EDD | 3-7-5-4-1-2 | 129304 | 18.48 | 00.05 |
| Total cost Ascending | 3-7-5-4-2-1 | 127410 | 16.73 | 00.05 |
| Descending | 1-2-4-5-7-5 | 117093 | 7.28 | 00.05 |

TABLE 9: Cost Breakup for various despatching rules for Experiment(C)

No. of Batches: 6

Weightage: 1 1 1 1 1

| Sequence | Rawmat Inventory Cost (Rs.) | Finished Goods Inventory Cost (Rs.) | Backorder Cost (Rs.) | Utility Cost (Rs.) | Changeover Cost (Rs.) | Accumulate cost (Rs.) |
|---|---|---|---|---|---|---|
| -2-4-5-7-3 | 98 | 2162 | 1355 | 106973 | 6504 | 117093 |
| -7-5-4-2-1 | 153 | 1409 | 1748 | 114978 | 9121 | 127410 |
| -7-5-4-1-2 | 119 | 1409 | 1748 | 117285 | 8741 | 129304 |
| -7-5-4-1-2 | 119 | 1409 | 1748 | 117285 | 8741 | 129304 |
| -1-4-5-7-3 | 109 | 2475 | 2869 | 109831 | 7065 | 122351 |
| -7-5-4-2-1 | 153 | 1409 | 1478 | 114978 | 9121 | 127411 |
| -2-4-5-7-3 | 98 | 2162 | 1355 | 106973 | 6504 | 117093 |
| -7-5-4-1-2 | 119 | 1409 | 1748 | 117285 | 8741 | 129304 |

# CHAPTER 5

## CONCLUSIONS AND EXTENSIONS

Main purpose behind a sequencing and scheduling exercise is to achieve a reasonably good sequence of product to be produced, which when cheduled meets the specified objective of the planner in the best manner. The planner should have provision to experiment with more than one objective and with minimum effort select a sequence which is best suited to his problem environment. The main purpose of developing the computerised sequencer is to provide flexibility with which it can handle various objectives and realistic cost evaluation schemes of different organisations. Thus the system tries to provide decision maker with an aid to handle planning problem without requiring an in-depth knowledge of theoretical aspect of sequencing and scheduling on the part of the user. However it should be noted that the quality of solution can only be judged in the presence of actual values of cost related data items.

Throughout the discussion, it is assumed that amount of raw materials required are procured in the beginning of the planning period. Availability of raw-material

if restricted, offers a new direction in which present work can be extended. Seperate routine which will give raw-material procurement and consumption schedule when coupled with this system, can be used to compute raw-material inventory cost. Like raw-material availability, in case of product interdependency, scheduling of a product is constrained by the availability of other product. Such product interdependency constraints may be incorporated in the scheduling algorithm.

Beside raw-material procurement and product interdependency, contribution made by blocked capital due to storage of, stable intermediate products to cost function may be incorporated so that more realistic situations can be handled.

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```
QUES 1:     Starting of the planning period :
            start time(hhmm format) :600
            start date :26
            month :6
            year :1984
QUES 2:     End of the planning period  :
            end time(hhmm format) :700
            end date  :15
            month  :7
            year  :1984
QUES 3:     Number of batches to be produced :6
QUES 4:     product_no:1:6
QUES 5:     batch size:1:1900.0
            product_no:2:1
            batch size:2:2000.0
            product_no:3:2
            batch size:3:1900.0
            product_no:4:3
            batch size:4:1500.0
            product_no:5:5
            batch size:5:1700.0
            product_no:6:4
            batch size:6:1400.0
QUES 5:     Select any one objective function:
            minimise total impementation cost/1/ :
            minimise total penalty due to late deliveries/2/ :
            minimise total utility cost/3/ :
            minimise total changeover cost/4/ :1
QUES 6:     What type of solution do you want ? :
            optimal/1/ :
            sub optimal/2/ :
            good/3/ :2
QUES 7:     which method do you want ? :
            non backtracking branch & bound/3/ :
            local neighbourhood search/4/ :4
            Choose the appropriate cost evaluation schemes :
QUES 8:     1) RAW MATERIAL INVENTORY COST :
            scheme/1/ :1
QUES 9:     weight(1) :1
```

QUES 10: 2) FINISHED GOODS INVENTORY COST :
scheme:partial delivery permitted/1/ :
partial delivery not permitted/2/ :1
QUES 11: weight(2) :1
QUES 12: 3) BACKORDER COST :
schemes: fixed cost + penalty per day/1/ :
fixed cost + penalty per :
article backordered/2/ :
fixed cost + penalty per day + :
penalty per article backordered :
penelty per units backordered/3/ :1
QUES 13: weight(3) :1
QUES 14: 4) CHANGE OVER COST :
schemes: cost proportional to changeover time/1/ :
cost varies with the incoming and
outgoing product/2/ :2
QUES 15: weight(4) :1
QUES 16: 5) UTILITY COST :
for steam,electricity etc
schemes:cost per unit consumed/1/ :
cost varying with the time of the day/2/ :
cost proportional to the peak level/3/ :2
for manpower cost of overtime/1/:1
QUES 17: weight(5) :1

# APPENDIX B

## VALIDITY CHECKS

Limited validity check for the answer, which is supplied by the user at dialogue time ( ref. Appendix A), is carried out by the program MAIN.SIM. SAFEI system checks the type of the supplied answer, i.e., if instead of an integer a real value is supplied the type check declares it as an error and question is repeated after an error message. For some of the questions, validity check is further extended as described below.

i) Whenever a date is asked for, supplied answer is accepted only if it lies between integers 1 and 31. Similarly for a month number, supplied integer is acceptable only if it lies in range 1 to 12. Once, date number and month number information is available for a particular day, a calender routine is called which checks that supplied number for the date does not exceed total number of days for corresponding month.

ii) Whenever information for time of a particular day is required, answer is acceptable in 'hhmm' format only. Further, number for hour must lie in range 0 to 24. Number supplied for minutes is accepted only if it is in the range 0 to 60.

iii) Whenever user supplies product number for a batch, valid range for the supplied integer is from 1 to total number of products that are produced in the plant.

iv) Whenever batch size information is supplied by the user, supplied positive real value is considered valid only if it is less than or equal to batch capacity for the corresponding product.

Similar validity checks are provided throughout SAFEI block of the program.

If, any of the validity check fails then an error message is falshed on the terminal screen and question is repeated.

++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++

# X Y Z CO. LTD.

## [illegible] INPUT

[illegible] PERIOD:
[illegible].25. [illegible].1984... 600HRS.
TO
[illegible].15. 7.1984... 600 HRS.

PRODUCT REQUIREMENT:

| | |
|---|---|
| PRODUCT P1 | 2000.00 KGS. |
| PRODUCT P2 | 1900.00 KGS. |
| PRODUCT P4 | 1500.00 KGS. |
| PRODUCT P5 | 1400.00 KGS. |
| PRODUCT P7 | 1600.00 KGS. |
| PRODUCT P3 | 1400.00 KGS. |

PLANT INFORMATION:
TOTAL PROCESSORS:19
TOTAL UTILITIES : 3

[illegible] PERIOD:
SMALLEST TIME PERIOD --> 60 MINS
ZERO WATT PROCESSING:APPLICABLE

OBJECTIVE: [illegible] TOTAL PENALTY DUE TO LATE DELIVERIES

## COST [illegible] SCHEMES:

[illegible] INVENTORY COST: BLOCKED CAPITAL COST
WEIGHT: 1

[illegible] GOODS INVENTORY COST:
[illegible]
WEIGHT: 1

[illegible] COST:
[illegible] + VARIABLE PENALTY FOR DAYSBACKLOGGED
+ [illegible] PENALTY FOR ARTICLES BACKORDERED
+ [illegible] PENALTY FOR UNITS BACKLOGGED
WEIGHT: 1

[illegible] COST :
COST VARYING WITH INCOMING AND OUTGOING PRODUCTS
WEIGHT: 1

UTILITY COST:
UTILITY 1: COST VARYING WITH TIME OF THE DAY
UTILITY 2: COST PROPORTIONAL TO LEVEL OF CONSUMPTION
UTILITY 3: MANPOWER COST
WEIGHT: 1

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SEQUENCING TECHNIQUE USED: [illegible] BACKTRACKING BRANCH & BOUND

| PRODUCT SEQUENCE | COST IN RS. |
|---|---|
| 1 | 53353.04 |
| 2 | 28009.13 |
| 4 | 3014.67 |
| 5 | 1885.57 |
| 7 | 3195.58 |
| 3 | 6697.57 |
| 5 1 | 57725.87 |
| 5 2 | 31370.90 |
| 5 4 | 5729.64 |
| 5 7 | 5223.69 |
| 5 3 | 9649.98 |
| 5 7 1 | 60851.11 |
| 5 7 2 | 38021.17 |
| 5 7 4 | 7702.62 |
| 5 7 3 | 12280.39 |
| 5 7 4 1 | 62748.40 |
| 5 7 4 2 | 40372.93 |
| 5 7 4 3 | 14133.42 |
| 5 7 4 3 1 | 77186.88 |
| 5 7 4 3 2 | 48771.11 |
| 5 7 4 3 2 1 | 117270.94 |

X Y Z CO. LTD.

DATA INPUT

PLANNING PERIOD:
DT.26. 5.1984... 5.00HRS.
TO
DT.15. 7.1984... [illegible] HRS.

PRODUCT REQUIREMENTS:

| | |
|---|---|
| PRODUCT 01 | 2000.00 KGS. |
| PRODUCT 02 | 1400.00 KGS. |
| PRODUCT 04 | 1500.00 KGS. |
| PRODUCT 05 | 1400.00 KGS. |
| PRODUCT 07 | 1000.00 KGS. |
| PRODUCT 03 | 1100.00 KGS. |

PLANT INFORMATION:
[illegible] PROCESSORS: 18
FINAL [illegible] : 3

[illegible] PERIOD:
[illegible] PERIOD ==> 90 MINS
[illegible] PROCESSING: APPLICABLE

[illegible] TOTAL PENALTY DUE TO LATE DELIVERIES

COST EVALUATION SCHEMES:

[illegible] INVENTORY COST: BLOCKED CAPITAL COST
WEIGHT: 1

[illegible] GOODS INVENTORY COST:
[illegible] DELIVERY ADDED
WEIGHT: 1

[illegible] COST:
[illegible] COST + VARIABLE PENALTY FOR DAYS BACKLOGGED
+ [illegible] PENALTY FOR ARTICLES BACKORDERED
+V [illegible] PENALTY FOR UNITS BACKLOGGED
WEIGHT: 1

CHANGEOVER COST:
COST VARYING [illegible] CHARGING AND OUTGOING PRODUCTS
WEIGHT: 1

UTILITY COST:
UTILITY 1: COST VARYING WITH TIME OF THE DAY
UTILITY 2: COST PROPORTIONAL TO LEVEL OF CONSUMPTION
UTILITY 3: [illegible] COST
WEIGHT: 1

[illegible] USING LOCAL NEIGHBOURHOOD SEARCH

| PRODUCT SEQUENCE | COST IN RS. |
|---|---|
| 2 1 4 5 7 3 | 116647.50 |
| 1 2 4 5 7 3 | 110333.02 |
| 2 1 [illegible] 5 7 3 | 116647.50 |
| 4 1 2 5 7 3 | 110071.23 |
| 1 4 2 5 7 3 | 109141.08 |
| [illegible] [illegible] [illegible] 5 7 3 | 110071.23 |
| [illegible] [illegible] 1 5 7 3 | 116647.50 |
| 5 1 4 2 7 3 | 118415.81 |
| 7 1 4 2 5 3 | 110711.88 |
| 3 1 4 2 5 7 | 123203.04 |
| 5 1 1 2 5 7 | 127759.71 |
| 3 2 1 4 5 7 | 128034.82 |
| 3 5 1 4 2 7 | 121951.88 |
| 3 7 1 4 2 5 | 122404.97 |